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Short Communication

Reliability of walking and stair climbing kinematics in a young obese population using a standard kinematic and the CGM2 model

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ABSTRACT

Background: Recently, the successor of the Conventional Gait Model, the CGM2 was introduced. Even though achievable reliability of gait kinematics is a well-assessed topic in gait analysis for several models, information about reliability in difficult study samples with high amount of subcutaneous fat is scarce and to date, not available for the CGM2. Therefore, this study evaluated the test–retest reliability of the CGM2 model for difficult data with high amount of soft tissue artifacts.
Research question: What is the test–retest reliability of the CGM2 during level walking and stair climbing in a young obese population? Is there a clinically relevant difference in reliability between a standard direct kinematic model and the CGM2?
Methods: A retrospective test–retest dataset from eight male and two female volunteers was used. It comprised standard 3D gait analysis data of three walking conditions: level walking, stair ascent and descent. To quantify test–retest reliability the Standard Error of Measurement (SEM) was calculated for each kinematic waveform for a direct kinematic model (Cleveland clinic marker set) and the CGM2.
Results: Both models showed an acceptable level of test–retest reliability in all three walking conditions. However, SEM ranged between two and five degrees (°) for both models and, thus, needs consideration during interpretation. The choice of model did not affect reliability considerably. Differences in SEM between stair climbing and level walking were small and not clinically relevant (<1°).
Significance: Results showed an acceptable level of reliability and only small differences between the models. It is noteworthy, that the SEM was increased during the first half of swing in all walking conditions. This might be attributed to increased variability resulting for example from inaccurate knee and ankle axis definitions or increased variability in the gait pattern and needs to be considered during data interpretation.

1. Introduction

The Conventional Gait Model (CGM) is a wide-spread model used in clinical gait analysis [1]. It was developed in the 1980s, and besides several strengths, faces some well-recognized limitations. Recently, the CGM2 was introduced as an evolution of the CGM [2]. This gait model was designed to be backward compatible with the original CGM while including technical advancements such as optimized hip joint center estimation [3,4], an inverse kinematic approach [5], the use of marker-cluster within an optimized marker set [6], upon some other changes. The CGM2 is implemented as an open-source python package (pyCGM2: https://pycgm2.github.io) and is freely available.

Motion-capture techniques that are based on skin-mounted markers are prone to errors introduced by inaccurate and/or inconsistent marker placement and soft tissue artifacts (STA) [7]. The latter are considered as relative movements of the skin (and markers) to underlying bone [8,9] and presumably increase with higher amount of subcutaneous fat. These errors can have a considerable effect on achievable reliability. Research has already addressed the question of reliability for several models during gait analysis in various populations [10] and certifies sufficient reliability in lean and acceptable results in overweight individuals [10,11].

One of the most fundamental changes in the CGM2, is the introduction of an inverse kinematics approach (IK) to calculate kinematic variables. In contrast to standard direct kinematics, IK positions a scaled generic biomechanical model in a pose that "best matches" experimental marker coordinates [12]. Even though achievable reliability

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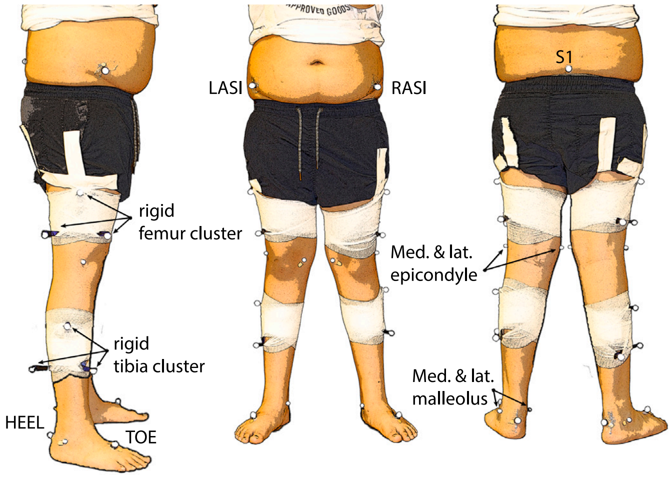

Fig. 1. The Cleveland clinic marker set used in this study for both, the direct kinematic model and the CGM2. Rigid base-plate cluster were used to track the femur and the tibia. Medial markers at the knee and ankle were used for static calibration. LASI/RASI: left and right anterior superior iliac spine; S1: first sacral vertebra.

is a well-assessed topic in gait analysis, information about reliability in difficult study samples with high amount of subcutaneous fat is scarce, limited to level walking, and not available for the CGM2. However, stair walking, as a common every-day-life activity, is also an important task relevant to the clinic and research.

Therefore, the aim of this study was to (i) assess the reliability of the CGM2 during level walking, stair ascent and descent in a study cohort with high amount of STAs [11] and (ii) to compare the achieved reliability to a well-known and commonly used direct kinematic model based on the Cleveland clinic marker set.

2. Methods

The retrospectively utilized dataset consisted of 3D gait analysis data (3DGA) of level walking from an earlier study at self-selected speed [11] and new data from metronome-assisted stair ascent/descent at ~110 steps per minute [13]. See Figure S1 in the supplementary material for details to the stair case. The dataset comprised eight male and two female volunteers (mean (standard deviation, SD); age: 15 (2.3) yrs, height: 171.5 (8.7) cm, mass: 100.8 (18.8) kg; BMI: 34.1 (4.1) kg/m^2) assigned to two 3DGA sessions which were separated by a minimum of one day and on average 3.4 (SD 2.0) days. Data were assessed by the same person, who had several years of experience. All participants were above the 95th percentile of the central Europe specific sex- and age-based body-mass-index (BMI) and considered as obese [14]. The utilized marker set was the Cleveland clinic marker set, which is depicted in Fig. 1. It was used to run the standard direct kinematic (DK) model and the third version of the CGM2 model (CGM2.3) embedded in Vicon Nexus (vers. 2.9.3.). Main differences between the DK-Cleveland model and CGM2 is the way of calculating kinematic variables (direct vs. inverse kinematics) and the different hip joint center estimation method utilized (Davis vs. Hara), respectively. For details to this topic the reader is referred to [2,3,15]. Five trials for each leg (in one session only three trials due to a technical problem) were used per participant and reduced to an averaged-waveform. To quantify reliability the Standard Error of Measurement [16] (SEM, derived from a 2-way repeated measures ANOVA) was calculated for each frame of the time-normalized kinematic waveforms and for the left and right side separately [16,17].

SEM values were then averaged for each waveform. The SEM values from all joints and both body sides, but separately for each anatomical plane were used to create boxplots. From these samples, the median served as an outcome measure (see Fig. 2). In line with McGinley et al. we defined differences greater than two degrees as clinically relevant [10].

3. Results

In general, SEM values ranged between one and seven degrees. Lowest values were seen for the frontal and highest for the transversal plane (see Fig. 2). The choice of model does not seem to affect reliability. Differences were below one degree in all variables (see results for stair descent in Fig. 3 and Figures S2-6 in the supplementary material for all walking conditions and both models). Stair ascent and descent both showed slightly increased SEM values for all three anatomical planes and both models compared to level walking, but averaged differences were again small (~1 degrees).

4. Discussion & conclusion

This study evaluated the test–retest reliability of the recently introduced successor of the Conventional Gait Model, the CGM2 [2]. For this purpose we assessed the achievable test–retest reliability with the CGM2 model during walking and stair climbing in an obese population and compared the results to a standard direct kinematic (DK) model, which was based on the Cleveland clinic marker set. Results showed an acceptable level of reliability for both models, but fall in

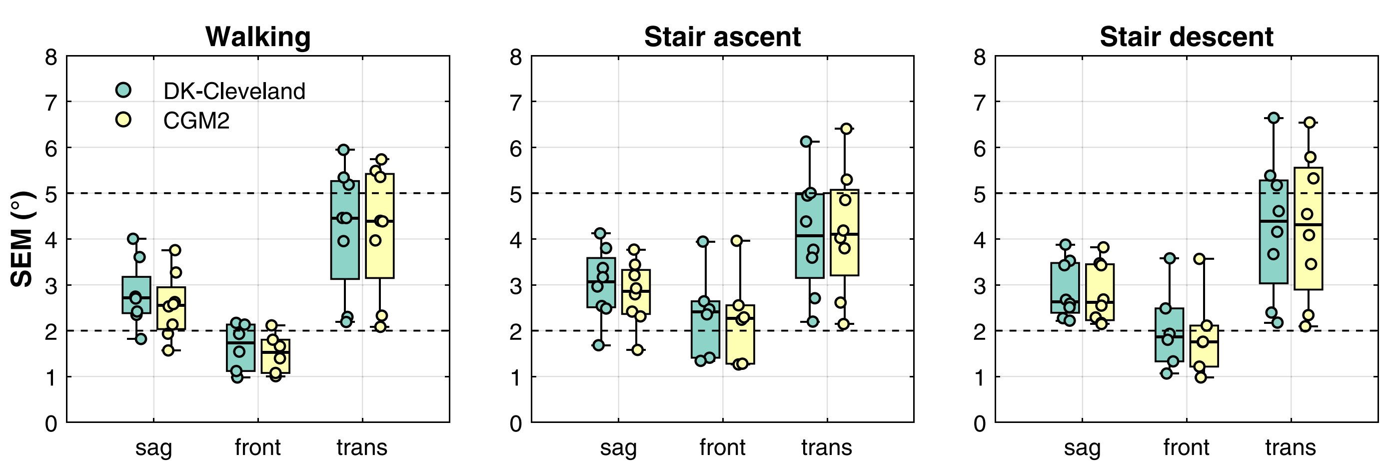

Fig. 2. Rain cloud boxplots showing the SEM-values (dots) pooled across all joints and both sides for each anatomical plane, three walking conditions, and both models. The boxplot represent, the minimum, maximum, the lower and upper quartile, and the median. The points represent the SEM for each kinematic waveform per anatomical plane and both body sides. The thresholds of 2 and 5 degrees proposed by McGinely et al. [10] are displayed as dashed lines.

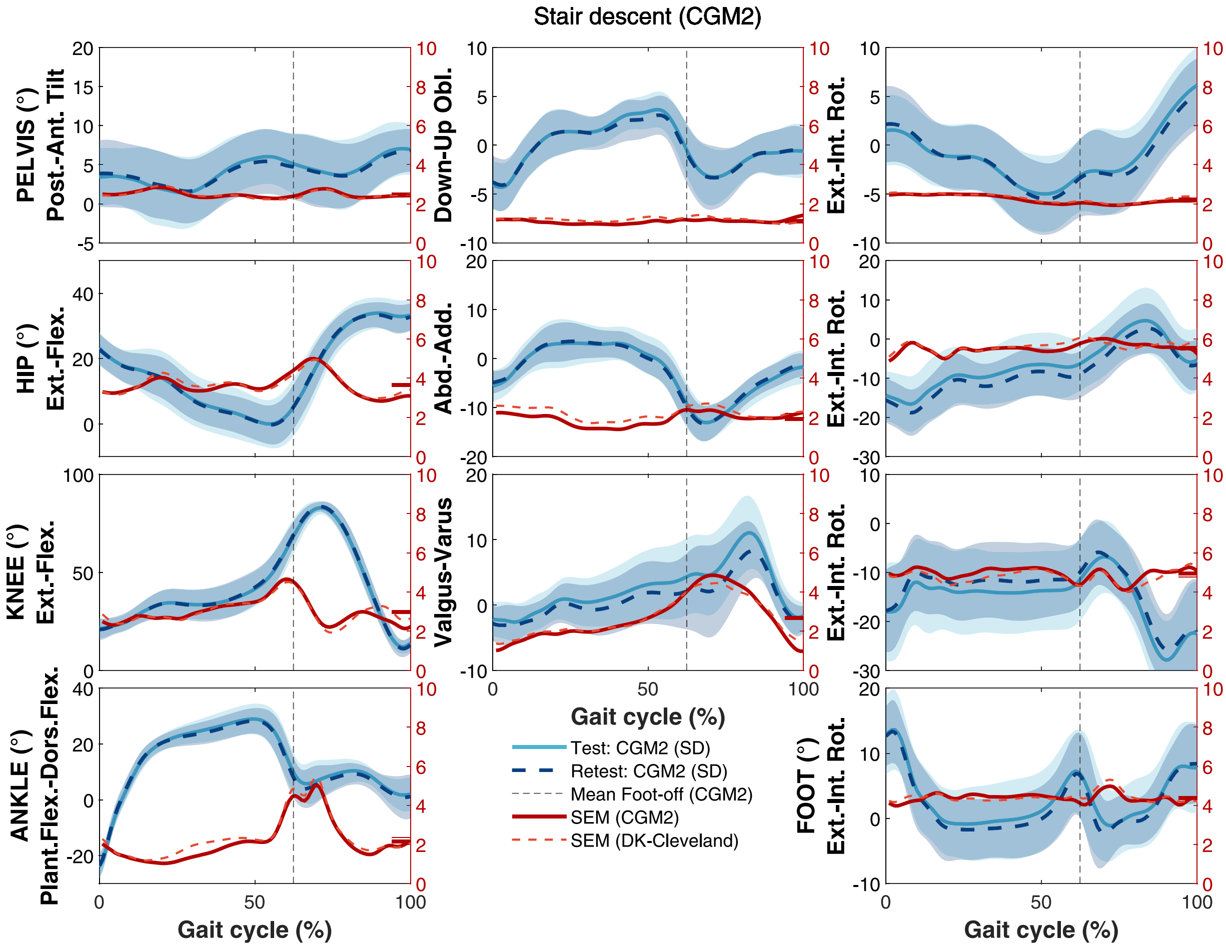

Fig. 3. Averaged kinematic waveforms during stair descent using the CGM2 model for the test (blue solid line) and retest (blue dashed line) sessions. Additionally, the SEM is shown on the secondary *y*-axis for both models (CGM2 and DK-Cleveland) to allow easier comparison. The small horizontal lines to the right indicate the average SEM per model. Note that the SEM was averaged between the left and right side for easier visualization. The vertical lines indicate the mean foot-off for the CGM2 model. The plots for walking and stair ascent can be found in the supplementary material.

the range of two to five degrees and, thus, need consideration during clinical interpretation [10]. Differences between the DK model and the CGM2 where on average below one degree. These differences could be explained by the different approaches used to calculate kinematics, but can be regarded as not clinically relevant. Given that the CGM2 incorporates several technical advancements compared to traditional DK models, our data clearly support the use of CGM2 from a reliability perspective. Its IK nature might also allow to re-process existing data with other marker sets and thus makes transition to a new model easier in clinical settings. During stair climbing higher accelerations might be assumed, which in turn could generate increased soft-tissue wobbling and higher STAs, and thus more variability in the data. Our results indicate that stair climbing compared to level walking produced slightly higher SEMs, but due to the small difference they can be considered as not clinically relevant. However, it is noteworthy, that the SEM increased in several kinematic variables during the first half of swing (e.g. see Fig. 3, ankle-flexion at ~60% gait cycle). This might indicate increased variability in that moment of time, which could either be due to an inaccurate knee and ankle axis definition or increased variability in the gait pattern. This peak is seen in all walking conditions, and is more pronounced during stair climbing and should be considered during data interpretation.

Some limitations need to be recognized. We have used laterally placed rigid clusters for the femur and tibia instead of the proposed skin cluster-markers [6]. Skin markers as proposed by Peters et al. [6] might be less prone to soft tissue wobbling, and thus could increase reliability. We have decided to calculate the SEM for each point of the entire waveform instead of using only discrete parameters. This has the advantage of offering more detailed information across the gait cycle but might be more sensitive to minor offsets in timing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.gaitpost.2020.10.017.

References

[1] R.J. Baker, F.Y. Leboeuf, J. Reay, M. Sangeux, The conventional gait model - success and limitations, in: B. Müller, S. Wolf (Eds.), Handbook of Human Motion, Springer, 2018, pp. 489–508, http://dx.doi.org/10.1007/978-3-319-14418-4_25.

[2] F. Leboeuf, R. Baker, A. Barré, J. Reay, R. Jones, M. Sangeux, The conventional gait model, an open-source implementation that reproduces the past but prepares for the future, Gait Posture 69 (2019) 235–241, http://dx.doi.org/10.1016/j.gaitpost.2019.04.015, http://www.sciencedirect.com/science/article/pii/S0966636219304333.

[3] R. Hara, J. McGinley, C. Briggs, R. Baker, M. Sangeux, Predicting the location of the hip joint centres, impact of age group and sex, Sci. Rep. 6 (1) (2016) 1–9, http://dx.doi.org/10.1038/srep37707.

[4] F. Leboeuf, J. Reay, R. Jones, M. Sangeux, The effect on conventional gait model kinematics and kinetics of hip joint centre equations in adult healthy gait, J. Biomech. (87) (2019) 167–171.

[5] T.W. Lu, J.J. O'Connor, Bone position estimation from skin marker co-ordinates using global optimisation with joint constraints, J. Biomech. 32 (2) (1999) 129–134, http://dx.doi.org/10.1016/S0021-9290(98)00158-4.

[6] A. Peters, M. Sangeux, M.E. Morris, R. Baker, Determination of the optimal locations of surface-mounted markers on the tibial segment, Gait Posture 29 (1) (2009) 42–48, http://dx.doi.org/10.1016/j.gaitpost.2008.06.007.

[7] A. Peters, B. Galna, M. Sangeux, M. Morris, R. Baker, Quantification of soft tissue artifact in lower limb human motion analysis: A systematic review, Gait Posture 31 (1) (2010) 1–8, http://dx.doi.org/10.1016/j.gaitpost.2009.09.004, http://linkinghub.elsevier.com/retrieve/pii/S0966636209006171.

[8] A. Cappozzo, Three-dimensional analysis of human walking: Experimental methods and associated artifacts, Hum. Mov. Sci. 10 (5) (1991) 589–602, http://dx.doi.org/10.1016/0167-9457(91)90047-2.

[9] V. Camomilla, R. Dumas, A. Cappozzo, Human movement analysis: The soft tissue artefact issue, J. Biomech. 62 (2017) 1–4, http://dx.doi.org/10.1016/j.jbiomech.2017.09.001.

[10] J.L. McGinley, R. Baker, R. Wolfe, M.E. Morris, The reliability of three-dimensional kinematic gait measurements: A systematic review, Gait Posture 29 (3) (2009) 360–369, http://dx.doi.org/10.1016/j.gaitpost.2008.09.003.

[11] B. Horsak, B. Pobatschnig, A. Baca, S. Greber-Platzer, A. Kreissl, S. Nehrer, B. Wondrasch, R. Crevenna, M. Keilani, A. Kranzl, Within-assessor reliability and minimal detectable change of gait kinematics in a young obese demographic, Gait Posture 54 (2017) 112–118, http://dx.doi.org/10.1016/j.gaitpost.2017.02.028.

[12] S. Delp, F. Anderson, A. Arnold, P. Loan, A. Habib, C. John, E. Guendelman, D. Thelen, Opensim: Open-source software to create and analyze dynamic simulations of movement, IEEE Trans. Bio-Med. Eng. 54 (11) (2007) 1940–1950, http://dx.doi.org/10.1109/TBME.2007.901024.

[13] G. Strutzenberger, A. Richter, M. Schneider, A. Mündermann, H. Schwameder, Effects of obesity on the biomechanics of stair-walking in children, Gait Posture 34 (1) (2011) 119–125, http://dx.doi.org/10.1016/j.gaitpost.2011.03.025.

[14] K. Kromeyer-Hauschild, M. Wabitsch, D. Kunze, F. Geller, H.C. Geiß, V. Hesse, A. von Hippel, U. Jaeger, D. Johnsen, W. Korte, K. Menner, G. Müller, J.M. Müller, A. Niemann-Pilatus, T. Remer, F. Schaefer, H.-U. Wittchen, S. Zabransky, K. Zellner, A. Ziegler, J. Hebebrand, Perzentile für den Body-mass-Index für das Kindes- und Jugendalter unter Heranziehung verschiedener deutscher Stichproben, Monatsschr. Kinderheilkd. 149 (2001) 807–818.

[15] R. Davis, S. Ounpuu, D. Tyburski, J. Gage, A gait analysis data collection and reduction technique, Hum. Mov. Sci. 10 (1991) 575–587.

[16] J.P. Weir, Quantifying test-retest reliability using the intraclass correlation coefficient and the SEM, J. Strength Cond. Res. 19 (1) (2005) 231, http://dx.doi.org/10.1519/15184.1.

[17] G. Atkinson, A.M. Nevill, Statistical methods for assessing measurement error (reliability) in variables relevant to sports medicine, Sports Med. 26 (4) (1998) 217–238, http://link.springer.com/article/10.2165/00007256-199826040-00002.